Studies of variation mechanisms of the Jovian radiation belt based on radio-interferometric and optical observations

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博士論文

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（電波干渉計と光学観測による
木星放射線帯変動メカニズムの研究）

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Abstract

Jupiter's synchrotron radiation (JSR) is the emission from relativistic electrons in the strong magnetic field of the inner magnetosphere, and it is the most effective probe for remote sensing of Jupiter's radiation belt from the Earth. Although JSR has been thought to be stable for a long time, recent intensive observations for JSR reveal short term variations of JSR with the time scale of days to weeks. *Brice and McDonough* [1973] proposed a scenario for the short term variations (hereafter the B-M scenario): the solar UV/EUV heating for Jupiter's upper atmosphere drives neutral wind perturbations and then the induced dynamo electric field leads to enhancement of radial diffusion. If such a process occurs at Jupiter, brightness distribution of JSR is also expected to change. That is, it is suggested that the induced dynamo electric field produces dawn-dusk electric potential difference and the dawn-dusk asymmetry in the electron spatial distribution. Then dawn-dusk asymmetry of the brightness distribution of JSR is produced. Previous studies have confirmed the existence of the short term variations in total flux density and its variation corresponds to the solar UV/EUV variations [*Miyoshi et al.*, 1999; *Tsuchiya et al.*, 2011]. However, confirmation of the scenario is limited. The purpose of this study is to examine the B-M scenario based on radio interferometer and optical observations, and reveal precise physical processes of the inner magnetosphere.

Total flux density of JSR

We made simultaneous observations of the Giant Metrewave Radio Telescope (GMRT) and the NASA InfraRed Telescope Facility (IRTF) in 2011 and 2014, in order to reveal whether the Jovian thermosphere responses to the solar UV/EUV and whether this actually causes variations of the total flux density and brightness distribution of JSR.

In the 2011 campaign, the total flux density of JSR at 610 MHz increased from Nov. 6 to Nov. 13 by about 5%, corresponding to the solar UV/EUV variations. Intensity of H_3^+also increased and temperature variation was estimated to be about 10 K. These results support the B-M scenario. On the other hand, peak position of brightness distribution of JSR shifted outwards, which is inconsistent with enhancement of radial diffusion. We considered the possibility that the outward shift might be due to the enhancement of some strong inside loss processes and examined it using the radial diffusion model from the Fokker-Planck equation. The results showed that the expected lifetime inside loss process is 10^5 sec for 10 MeV electrons. We examined the lifetime for the interactions with the Halo dust and waves. The expected lifetime for interaction with the Halo dust is too slow for the strong inside loss process (the order of 10^9 sec), however, if charged dust acts as coulomb interaction, loss rate of the dust interaction might be faster. Concerning the wave particle interaction, the expected strong diffusion limit is about 700 sec around the peak positions of JSR [*Schulz*, 1974] which is sufficiently shorter than the required lifetime, the interaction also might cause the inside loss process.

In the 2014 campaign, the total flux density, rotational temperature of H_3^+, and solar EUV flux showed a similar decreasing trend until Jan. 10. These results support the B-M scenario. On the other hand, the total flux density and the temperature increased after Jan. 12 even when the solar EUV flux decreasing almost monotonically. A numerical simulation study of the Jovian upper atmosphere suggests that the high latitude Joule heating is induced by solar EUV radiation, and it affects the mid-low latitude thermosphere [*Tao et al.*, 2014]. The enhancement of the temperature and the total flux density after Jan. 12 might be caused by the high latitude heating. In addition to that, if high latitude heating is caused by some processes other than the solar UV/EUV, it is expected that this also affects the mid-low latitude temperature and the radiation belt: one of such the effects might be brought by enhancement of field aligned currents flowing into the high latitude region, which is driven by some global magnetospheric variations.

From combined simultaneous observations, we found that the solar UV/EUV enhancement causes the variations in thermospheric temperature and intensity of JSR had correlation, which is consistent with the B-M scenario. It is also suggested that two points should be taken into account in addition to the original B-M scenario: strong inside loss processes and the high latitude heating effect on the mid-low latitude thermosphere.

Averaged dawn-dusk asymmetry of JSR

We made the Very Large Array (VLA) data analysis to investigate the effect of the diurnal wind system on averaged dawn-dusk peak emission ratio. From the VLA data analysis, it is found that averaged dawn-dusk ratio is larger than unity, which supports the B-M scenario. Then, we estimated the diurnal wind velocity from the observed dawn-dusk ratio by using the equatorial brightness distribution model of JSR constructed in this study. The estimated neutral wind velocity is a few ten m/s, which reasonably corresponds to the numerical simulation of Jupiter's upper atmosphere [*Tao et al.*, 2009]. It is therefore suggested that the averaged dawn-dusk asymmetry is caused by the steady diurnal wind system and its wind velocity is expected to be a few ten m/s.

Short term variations in the dawn-dusk asymmetry of JSR

We tried to find the mechanism of short term variations in the dawn-dusk asymmetry of JSR. The correlation between solar EUV flux and dawn-dusk ratio of JSR was examined by using the VLA archived data observed in 2000. From the data analysis, it is shown that variations of the dawn-dusk ratio did not correspond to those of the solar UV/EUV flux: the observed variation feature of the dawn-dusk ratio cannot be simply explained by the solar UV/EUV heating, which is not consistent with the B-M scenario. The atmospheric modeling study by *Tao et al.* [2009] also suggests that neutral wind variation corresponding to the observed solar UV/EUV variation is insufficient to cause the observed short term variations of the dawn-dusk ratio.

Then, as a new candidate, effect of a global dawn-dusk electric field in the Jovian magnetosphere was examined. We analyzed the simultaneous observational data of the GMRT and HISAKI in 2014. We used dusk-dawn EUV emission ratio of the Io torus as an index of dawn-dusk electric field. We found that the dusk-dawn emission ratio of the Io plasma torus showed local maximum around Jan. 2 and Jan. 12, and increase and decrease tendencies of the dusk-dawn ratio of JSR also corresponded to those of the Io plasma torus. The variations of dusk-dawn ratio of JSR were about

0.04, which corresponded to the electric field variations of 4 mV/m. This value is consistent with *Schneider and Trauger* [1995], which reported the fluctuation of dawn-dusk electric field of ± 2 mV/m from the observations of the Io plasma torus. Hence, the dawn-dusk electric field is expected to affect the short term variations in the dawn-dusk asymmetry of JSR. The driving mechanism of the dawn-dusk electric field is still unknown, however solar wind dynamic pressure and/or plasma outward flow from the Io orbit might be the candidate of the generation of the dawn-dusk electric field.

Throughout this study, especially following points are deferred to future studies which lead to further understanding of physical mechanisms in the Jovian radiation belt and thermosphere. More precise temperature measurement and detection of the wind velocity variations are needed for further confirmation of the B-M scenario, which provide the observational evidence whether the thermospheric disturbance of temperature and wind velocity can cause the radial diffusion of energetic electrons. It is also expected that if some other processes cause enhancement of field aligned currents flowing into the high latitude region, such processes drive the high latitude heating and affect the mid-low latitude thermosphere. Furthermore, particle precipitation into the mid-low latitude, heat transportation from the high latitude, and atmospheric gravity wave should take into account. These attempts are directly linked to understand the heating mechanism of the Jovian thermosphere which has been unknown for a long time.